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Buried Gas Pipeline Inspection with EMAT's

Abstract

The electromagnetic, noncontact transducer (EMAT) is particularly well suited to ultrasonic inspection problems where it is difficult or impossible to couple the sound into the object being tested through a liquid or grease layer. For inspecting buried natural gas pipelines, the inspection process must be carried out by a self contained instrument package blown through the pipe by the gas stream. This demands that the transducers move with speeds of 10 to 20 mph along the pipe and give continuous operation over distances of 50 to 100 miles. Under the sponsorship of the American Gas Association, it has been demonstrated that EMAT's designed to launch and detect Lamb waves which propagate around the circumference of the pipe can meet these inspection requirements. The special transducers designed for this purpose used conductors laid down in a meander line configuration with the spacing between the adjacent lines chosen to be equal to one half of the wave length of the first antisymmetric Lamb wave mode of the pipe wall (a flexure wave) at the operating frequency of 130 KHz. These Lamb waves were focused into a beam of energy and directed around the pipe circumference so that when they encountered a longitudinal stress corrosion crack or a region of pit corrosion, the reflection of energy could be used to detect the location and approximate size of the defect. Both transmitters and receivers were fabricated and the detection of simulated defects machined into the outside surface of a 36-inch dia. by 40-foot long section of pipe buried at the Science Center has been demonstrated. In addition, special experiments were performed to demonstrate that the EMAT's performed satisfactorily when the metal moves past them at speeds up to 20 mph (27 ft/sec, 1/3 inches/millisecond).

Keywords

Nondestructive Evaluation

Disciplines

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BURIED GAS PIPELINE INSPECTION WITH EMAT'S

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ABSTRACT

The electromagnetic, noncontact transducer (EMAT) is particularly well suited to ultrasonic inspection problems where it is difficult or impossible to couple the sound into the object being tested through a liquid or grease layer. For inspecting buried natural gas pipelines, the inspection process must be carried out by a self contained instrument package blown through the pipe by the gas stream. This demands that the transducers move with speeds of 10 to 20 mph along the pipe and give continuous operation over distances of 50 to 100 miles. Under the sponsorship of the American Gas Association, it has been demonstrated that EMAT's designed to launch and detect Lamb waves which propagate around the circumference of the pipe can meet these inspection requirements. The special transducers designed for this purpose used conductors laid down in a meander line configuration with the spacing between the adjacent lines chosen to be equal to one half of the wave length of the first antisymmetric Lamb wave mode of the pipe wall (a flexure wave) at the operating frequency of 130 KHz. These Lamb waves were focused into a beam of energy and directed around the pipe circumference so that when they encountered a longitudinal stress corrosion crack or a region of pit corrosion, the reflection of energy could be used to detect the location and approximate size of the defect. Both transmitters and receivers were fabricated and the detection of simulated defects machined into the outside surface of a 36-inch dia. by 40-foot long section of pipe buried at the Science Center has been demonstrated. In addition, special experiments were performed to demonstrate that the EMAT's performed satisfactorily when the metal moves past them at speeds up to 20 mph (27 ft/sec, 1/3 inches/millisecond).

Natural gas pipelines that have been buried for some time are subject to corrosion and stress corrosion cracking which may cause leaking after extended service. In order to find areas where leaking may soon occur, it is desirable to inspect the pipeline periodically with a self-contained instrument package that can be blown through the pipe by the gas stream and which can record the presence and location of potentially weak areas. Current devices to accomplish this inspection use magnetic flux leakage techniques to detect localized thinning of the pipe wall, but these turn out to be insensitive to longitudinal stress corrosion cracks and to non-localized regions of generalized corrosion. Recently, the American Gas Association has sponsored a program at the Science Center to determine if the new ultrasonic technology based on Electromagnetic Acoustic Transducers (EMAT's) could be used in the remote environment of a buried gas pipeline and give new and different information on the defects in the pipe wall.

Figure 1 lists the requirements set down by the gas association which any ultrasonic inspection device must meet in order to be useful. It also gives the characteristics of the EMAT based system which make it a viable concept for this application.

Figure 2 shows the basic principles of operation. A meander coil EMAT is placed between the poles of a permanent magnet (or an electromagnet) and held in proximity to the ID of the pipe. There it excites ultrasonic Lamb waves in the pipe wall which propagates around the circumference of the pipe in both a clockwise and a counterclockwise direction. If a defect lies anywhere on the circumference, it

will reflect a portion of the Lamb wave energy back toward the transmitter. By placing a meander coil receiver transducer between the poles of the same magnet as was used for the transmitter, it can pick up the reflection from the defect in the typical ultrasonic pulse-echo mode of inspection. One magnet with a receiver and a transmitter could, in principle, inspect the entire pipe circumference, but attenuation and beam spreading make it more practical to utilize three transducer pairs positioned at equal angular intervals around the circumference as is shown on the right-hand side of the figure.

Figure 3 shows that two types of Lamb waves can be excited in the pipe walls at the low frequencies for which the wave length is comparable to the pipe wall thickness. At the single frequency of 130 KHz, these two Lamb waves have quite different propagation velocities and the different distortions shown on Fig. 3. The differing velocities of propagation mean different wave lengths so that the spacing of the meander coils in the transducers is only about 3/8 inches for the flexural wave and about 5/8 inches for the longitudinal wave case.

Figure 4 shows an example of the pulse-echo signals resulting from some simulated defects machined into the pipe wall. In this case, separate transmitter and receiver transducers and magnets were used. The numbers labeling each RF pulse signal displayed on the oscilloscope photographs are associated with the wave paths shown in the drawing of a cross-section of the pipe. Figure 5 shows photographs of the top and bottom views of the experimental inspection system as it entered a 40-foot long section of a 36-inch diameter test pipe.

Figure 6 lists the accomplishments attained by the Science Center program to date. It can be concluded that the EMAT type of transducer can be used to detect longitudinal stress corrosion cracks and generalized pipe wall thinning in buried pipelines. It now becomes necessary to install this technology on an inspection device designed to operate in real pipelines of several miles in length.

Acknowledgement

This work was supported by the American Gas Association, contract PR-73-57.

REQUIREMENTS

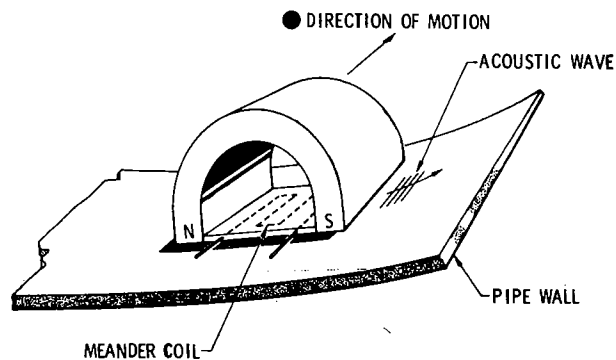
- DETECT EXTERNAL DEFECTS FROM AN INTERNAL SENSOR
- INSPECT ENTIRE LENGTH (20 - 100 MILES) AND CIRCUMFERENCE (18 - 48 IN. DIA.)
- ACCOMMODATE SHARP TURNS
- TRAVEL AT GAS FLOW SPEEDS (10 - 20 MPH)
- SELF-CONTAINED DATA PROCESSING AND RECORDING
- DEFECT CHARACTERIZATION

ULTRASONIC INSPECTION SYSTEM

- EMATs OPERATE AT HIGH SPEED
- CIRCUMFERENTIAL LAMB WAVES SENSITIVE TO LONGITUDINAL CRACKS
- FEW TRANSDUCERS NEEDED TO INSPECT ENTIRE CIRCUMFERENCE
- MAGNETIC FIELD NEEDED ONLY AT TRANSDUCERS
- COMPACT SHAPE POSSIBLE FOR SHARP TURNS
- ULTRASONIC SIGNAL ANALYSIS FOR DEFECT IDENTIFICATION

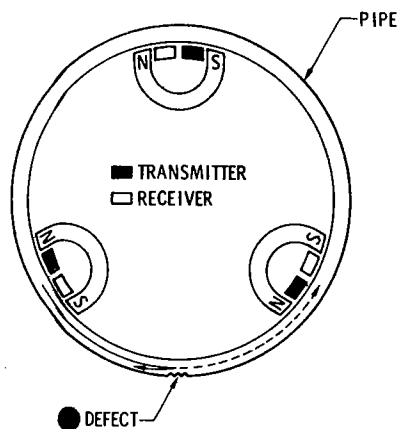
Figure 1. Gas Association requirements for ultrasonic inspection devices and characteristics of EMAT based system.

NONCONTACT ELECTROMAGNETIC TRANSDUCER



HIGH SPEED MOTION POSSIBLE

INSPECTION PRINCIPLE

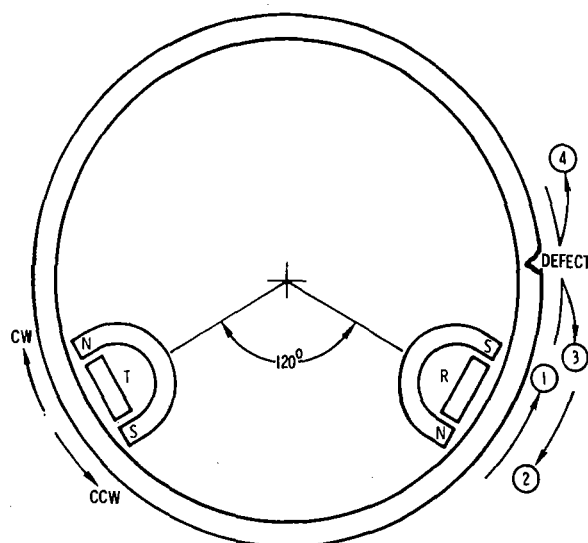
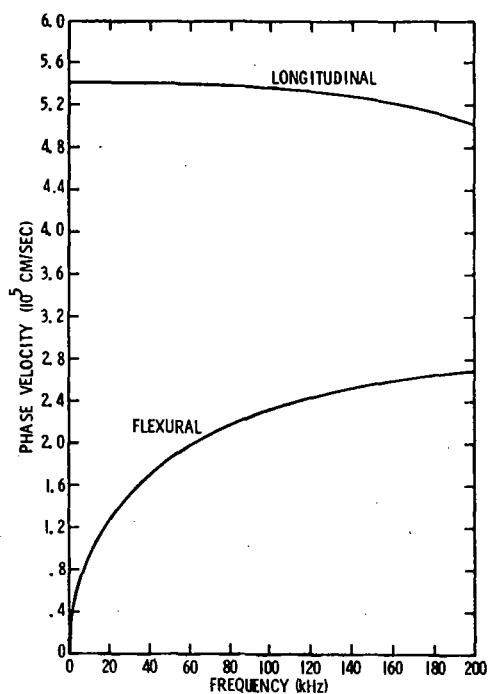


DEFECT CHARACTERIZATION POSSIBLE

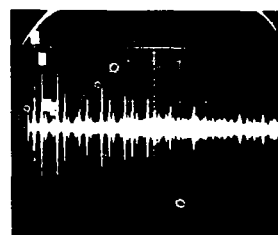
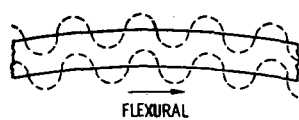
LAMB WAVES LAUNCHED AND DETECTED AT EACH MAGNET

- DEFECTS LOCATED BY PULSE-ECHO REFLECTION TECHNIQUES
- AT 20 MPH TRANSDUCERS MOVE 0.3 INCHES/MILLISECOND

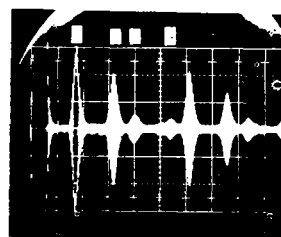
Figure 2. Basic principles of operation for an EMAT based system.



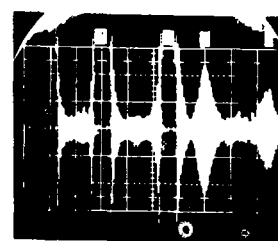
- EMAT'S GENERATE CLOCKWISE AND COUNTERCLOCKWISE LAMB WAVES
- FULL CIRCUMFERENCE SIGNALS USEFUL FOR NORMALIZING SIGNALS



1 ms/DIV



200 μs/DIV

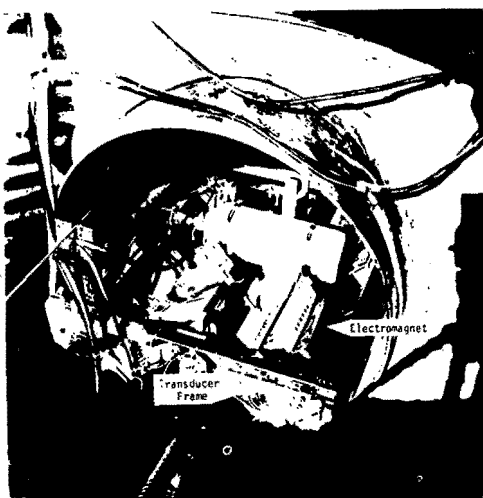


100 μs/DIV

- LAMB WAVES ARE VIBRATIONAL MODES OF A PLATE IN WHICH THE ENERGY IS TRAPPED BETWEEN THE TWO BOUNDARIES OF THE PLATE
- FOR PIPELINE INSPECTION A FREQUENCY OF 130 kHz EXCITES LAMB WAVES THAT HAVE A WAVE LENGTH COMPARABLE TO THE PIPE WALL THICKNESS

Figure 3. Lamb waves.

Figure 4. Pipe echo signals.



PHOTOGRAPH OF VEHICLE ENTERING A 36 INCH DIAMETER PIPE
TWO EMAT'S LOCATED AT 4 AND 8 O'CLOCK



UNDERSIDE OF ONE EMAT MAGNET SHOWING A RECEIVER BETWEEN
THE POLE PIECES AND A TRANSMITTER UNDER ONE POLE PIECE.

Figure 5. Experimental inspection vehicle.

CONTRACT SPONSORED BY THE AMERICAN GAS ASSOCIATION

- PHASE I DEMONSTRATION OF FEASIBILITY OF USING EMATs AND LAMB WAVES
- PHASE II DEMONSTRATE OPERATION FROM A MOVING PLATFORM IN A BURIED PIPE
- PHASE III DEMONSTRATE TECHNIQUES FOR DEFECT CHARACTERIZATION AND HIGH SPEED OPERATION
- PHASE IV OPTIMIZE SYSTEM COMPONENTS AND DEMONSTRATE OPERATION ON REAL DEFECTS
- PHASE V CONSTRUCT EXPERIMENTAL INSPECTION SYSTEM WITH ON-BOARD RECORDING
- PHASE VI GENERATE QUANTITATIVE DATA FOR SENSITIVITY DETERMINATIONS

Figure 6. Accomplishments.